MEASUREMENT OF SENSIBLE AIR-GROUND INTERFACE TEMPERATURES

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ABSTRACT

Several methods of measuring the sensible air-ground interface temperature are discussed. The sensible air-ground interface temperature is here defined as that temperature of the interface as indicated by properly exposed temperature sensors. A comparison is made between the temperature of a copper plate in direct contact with the soil surface, and that indicated by the bottom plate of a "Suomi-Kuhn Economical Net Radiometer" at night. Results using several types of temperature sensors are discussed. Temperatures obtained from a copper plate with a thermohm sensor and the lower plate of a modified net radiometer show an average difference of 0.3° C.

1. INTRODUCTION

It is axiomatic that changes in the temperature of the air near the ground are influenced directly by changes in the temperature of the ground surface. Most of the methods commonly used in minimum temperature forecasting either ignore soil temperatures completely [1], assume that the parameters in a given location are constant [2], or use values obtained from published tables without considering local variations [3].

Soil composition, density, moisture content, etc., vary with time and space. These variables determine the thermal characteristics of a given parcel of soil, and hence are major contributing factors to the radiative temperature of the soil surface. The need for continuous measurements of soil parameters is obvious.

Measurement of the true air-soil interface temperature is a very difficult thing, because it is almost impossible to locate a sensor at the true interface, and because of the large spatial fluctuations of the parameter. If one can measure the sensible air-ground interface temperature at a given spot, fluctuations of this value will be a good index of the over-all variability in the given area. This is the premise for the following work.

2. METHODS OF MEASURING SENSIBLE TEMPERATURE OF AIR-GROUND INTERFACE

One of two methods is usually used to determine the surface temperature. The most common is to lay either an alcohol-in-glass or a mercury-in-glass thermometer on the surface [4] and assume that the indicated temperature is the desired value. This technique has several disadvantages: (1) The bulb of the thermometer, if laid on the soil, is radically affected by wind. (2) The glass bulb of the thermometer is subject to marked "greenhouse effect" (radiative heating during incoming radiation periods and radiative cooling during outgoing radiation periods). (3) If the thermometer is partially buried, it gives a mean temperature of the upper layers of soil depending upon the depth to which the bulb is buried. (4) It requires manual reading and does not permit obtaining a continuous record. (5) Dirt carried by wind will bank around the thermometer bulb resulting in a continuous change of the depth of the bulb in the soil.

The second technique is to lay a fine wire thermocouple on the ground surface [5]. This method eliminates many of the radiative effects, but is subject to cooling and warming by the wind when direct contact with the soil is not maintained. The thermocouple is also affected greatly by drifting soils.

The device described below was designed in an attempt to minimize the above effects, and also to enable continuous recording of fluctuations in the temperature. It is not believed that this device will determine values to within tenths of a degree, but the accuracy is of the same order of magnitude as that of other parameters used in the temperature forecast studies being conducted by the authors.

A copper plate 3 x 4 inches in area and about 0.05 inch thick was made containing an enclosure for the sensing element (see fig. 1). Copper was chosen because it has about the highest conductivity of the cheaper metals and also because, as it oxidizes, the surface becomes similar in color to that of moist soil. A thinner sheet of copper was used in earlier tests, but it tended to buckle and would not maintain good contact with the ground. The copper plate was laid on top of barren soil with the lower surface in firm contact with the soil and the upper surface subject to the same effects of wind, radiation, and moisture as the

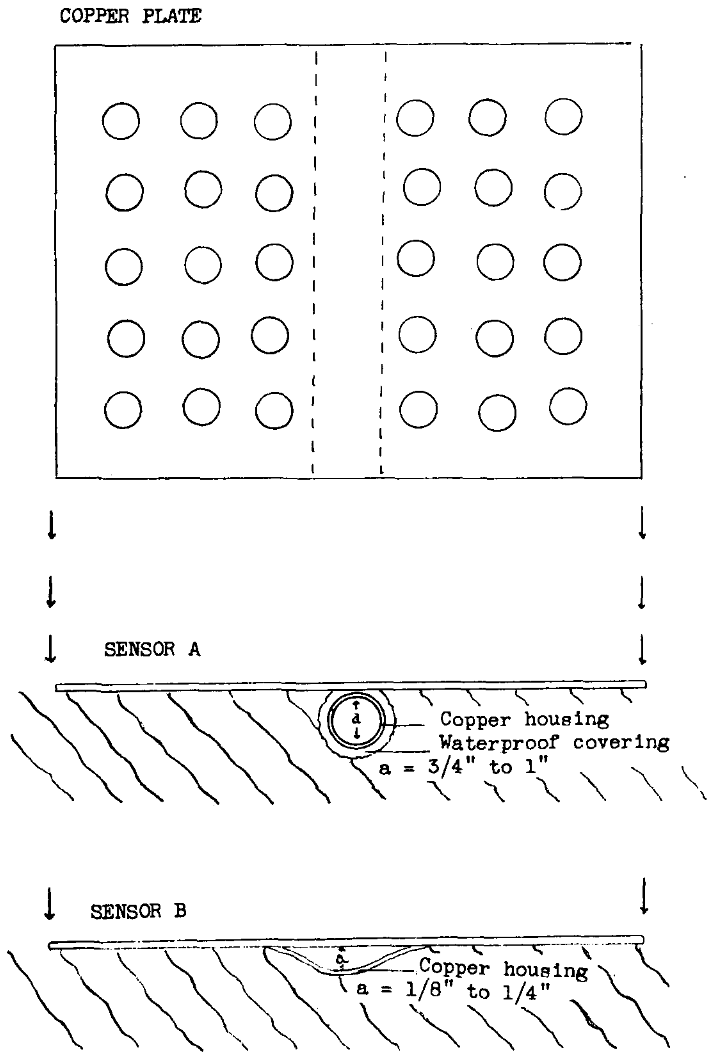

FIGURE 1.—Diagram showing copper plate with holes bored at ½-inch intervals, and arrangement of three types of temperature-sensing elements when plate was placed in contact with soil. Sensor A: soil thermograph; Sensor B: thermistor or small thermohm.

surrounding soil surface. To prevent the plate acting as a water shield to precipitation or a hindrance to evaporation of soil moisture, ¼-inch holes were drilled at ½-inch intervals over the entire surface. Three types of temperature sensors were tested in the plates.

A small copper plate with a mercury thermometer as a sensor was used by Ramanathan [6] as a device to measure surface temperatures. Geiger [5] considers this the best way to use a mercury thermometer to measure ground temperatures.

MODIFIED SOIL THERMOGRAPH

The first sensor tested was a Gotham Instrument Company soil thermograph using a gas-filled Bourdon-tube sensor. The sensing element in this instrument is about ¾ inch in diameter and therefore it was found necessary to try to insulate the bulb enclosure on the plate from the ground, allowing only the wings of the plate to lie in direct contact with the ground. Seven or eight thicknesses of asbestos were glued to the lower part of the enclosure (fig. 1A), and this was then painted with a waterproof white paint. Continuous testing of this modified soil thermograph over a period of 2 years has shown satisfactory results. Occasional checks on the accuracy of the sensing element have been made by inserting the bulb of a mercury-in-glass thermometer under the edge of the copper plate.

THERMISTOR SENSOR

The second sensor tested with the copper plate was a No. 419 coated Air Force radiosonde thermistor. The thermistor was inserted in a piece of polyethylene tubing to insure a moisture-resistant seal. The tubing with the enclosed thermistor was then sealed in the copper housing with a water-resistant plastic sealer. The small size of the thermistor enabled the use of a plate which lay nearly flat on the ground over the entire surface with only a slight indentation in the soil of ⅛ to ¼ inch (fig. 1B).

THERMOHM SENSOR

The third sensor tested was a ¼-inch diameter thermohm used with a six-point Bristol recorder. The thermohm sensor was sealed in the copper housing with the plastic sealer. The plate was the same as in figure 1B, but with an indentation in the soil surface of about ⅜ inch.

USE OF NET RADIOMETER FOR INTERFACE TEMPERATURE MEASUREMENT

A completely different technique for measuring the sensible soil-surface temperature was used as a check on the soil plate measurements. Temperatures indicated by the bottom plate of a Suomi-Kuhn Economical Net Radiometer [7], which was mounted about 3 feet above the ground, were used as an indication of the sensible soil-surface temperatures at night. A modification of the Suomi-Kuhn net radiometer was constructed using a piece of styrofoam for the housing and Saran Wrap for the plastic covers. It was found that these modifications made possible longer exposures of the instrument to the weather. The tendency of moisture to accumulate between the two plastic covers of the net radiometer was not nearly as marked in the modified instrument. It was possible to leave the instrument exposed for as much as 3 weeks to the winter weather, including some snows, without changing the Saran Wrap covers. Use of the polyethylene covers required changing nearly every day because of dew and frost deposits. Comparison of the readings obtained from the two instruments showed that the net radiation data recorded by each instrument were almost identical when using thermistors as sensors.

3. COMPARISON OF METHODS

A comparison of the three methods of measuring the

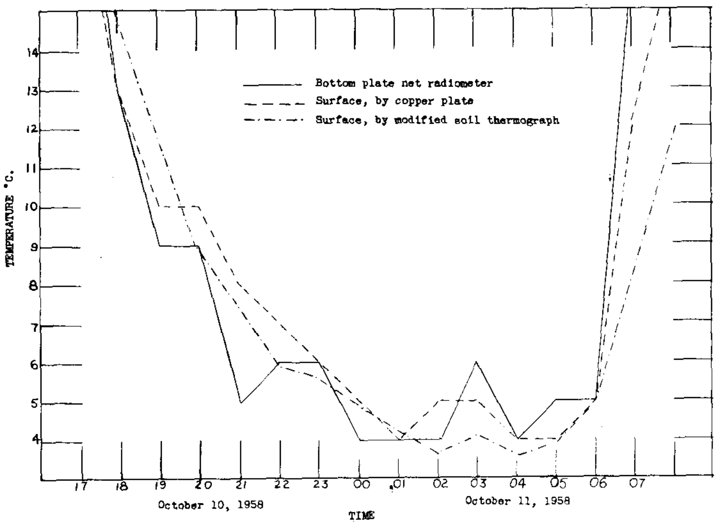

FIGURE 2.—Comparison of "sensible soil-surface temperature" of dry soil as recorded by bottom plate of "Suomi-Kuhn Economical Net Radiometer", a copper plate with thermistor sensor, and the modified soil thermograph.

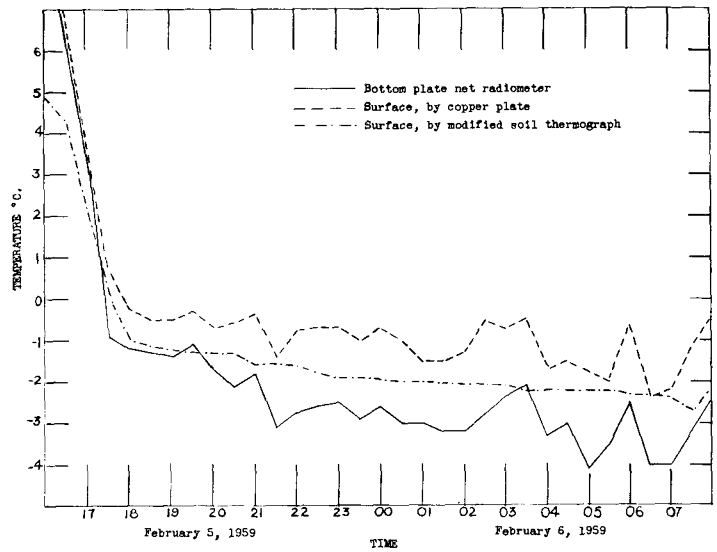

FIGURE 3.—Comparison of "sensible soil-surface temperature" of moist soil as recorded by bottom plate of a "Suomi-Kuhn Economical Net Radiometer", a copper plate with thermistor sensor, and the modified soil thermograph.

TABLE 1.—*Hourly comparison during nighttime hours of "sensible soil-surface temperature" (°C.) as recorded by the bottom plate of a modified "Suomi-Kuhn Economical Net Radiometer" and a copper plate using a ¼-inch thermohm sensor, over a period of 1 week*

Sensor Type	Time														
	p.m.						a.m.								
	6	7	8	9	10	11	0	1	2	3	4	5	6	7	8
November 29, 1959															
Soil Plate								−4.9	−5.1	−5.6	−6.0	−6.1	−6.0	−6.0	−5.5
Net Radiometer								−4.3	−5.1	−5.6	−7.2	−7.4	−6.7	−6.4	−6.5
Difference								−0.6	0	0	+1.2	+1.3	+0.7	+0.4	+1.0
November 29–30, 1959															
Soil Plate	0.4	−1.0	−1.9	−2.8	−3.4	−3.9	−4.1	−4.0	−3.9	−3.2	−2.4	−3.0	−4.0	−4.5	−3.4
Net Radiometer	0.4	−2.2	−2.5	−2.7	−3.4	−4.3	−4.0	−4.3	−4.5	−4.1	−3.2	−2.3	−3.5	−5.2	−3.3
Difference	0	+1.2	+0.6	−0.1	0	+0.4	+0.1	+0.3	+0.6	+0.9	+0.8	−0.7	−0.5	+0.7	+0.1
November 30–Dec. 1, 1959															
Soil Plate	1.6	0.2	−0.9	−1.7	−2.2	−2.6	−2.9	−3.5	−3.7	−4.0	−4.2	−4.4	−5.3	−4.5	−4.3
Net Radiometer	1.8	−1.2	−1.2	−2.5	−2.1	−3.3	−2.4	−3.8	−3.7	−3.6	−5.5	−4.6	−5.4	−4.3	−4.2
Difference	−0.2	+1.4	+0.3	−0.8	−0.1	−0.7	−0.5	+0.3	0	−0.4	+1.3	+0.2	+0.1	−0.2	−0.1
December 1–2, 1959															
Soil Plate	1.0	0	−1.2	−1.7	−1.1	−2.1	−2.4	−3.2	−3.9	−4.0	−4.0	−4.5	−4.8	−4.5	−3.9
Net Radiometer	−0.2	−0.9	−1.3	−2.0	−1.3	−1.1	−1.7	−3.9	−4.5	−4.9	−4.5	−5.4	−5.9	−5.1	−4.7
Difference	+1.2	+0.9	+0.1	+0.3	+0.2	−1.0	−0.7	+0.7	+0.6	+0.9	+0.5	+0.9	+0.9	+0.6	+0.8
December 2–3, 1959															
Soil Plate	1.2	0	−0.9	−1.3	−2.2	−3.0	−3.0	−3.8	−4.2	−4.5	−4.5	−5.0	−5.0	−5.2	−4.5
Net Radiometer	0.8	−0.9	−1.1	−2.0	−3.1	−3.7	−3.0	−4.1	−5.5	−5.8	−5.0	−5.3	−5.2	−4.3	−5.1
Difference	+0.4	+0.9	+0.2	+0.7	+0.9	+0.7	0	+0.3	+0.7	+1.3	+0.5	+0.3	+0.2	−0.9	+0.6
December 3–4, 1959															
Soil Plate	0	−1.3	−2.8	−3.6	−4.0	−5.0	−5.5	−5.8	−6.3	−6.7	−7.0	−7.8	−7.2	−8.3	−7.4
Net Radiometer	−0.2	−1.3	−3.5	−4.3	−3.7	−4.5	−6.3	−4.9	−5.8	−6.6	−6.7	−8.3	----------	−8.6	−7.8
Difference	+0.2	0	+0.7	+0.7	−0.3	−0.5	+0.8	−0.9	−0.5	−0.1	−0.3	+0.5	----------	+0.3	+0.4
December 4–5, 1959															
Soil Plate	−3.0	−4.0	−5.0	−6.0	−5.3	−7.1	−7.9	−7.5	−8.2	−8.4	−9.0	−9.0	−9.2	−9.3	−7.7
Net Radiometer	−2.8	−3.5	−5.0	−5.1	−6.3	−7.9	−8.2	−8.3	−9.0	−9.3	−10.1	−9.6	−9.5	−9.7	−7.7
Difference	−0.2	−0.5	0	−0.9	+1.0	+0.8	+0.3	+0.8	+0.8	+0.9	+1.1	+0.6	+0.3	+0.4	0
December 5, 1959															
Soil Plate	−3.0	−1.5	−4.9	−5.8	−6.0	−6.2	−6.4								
Net Radiometer	−4.1	−2.2	−5.0	−6.2	−6.6	−7.2	−7.4								
Difference	+1.1	+0.7	+0.1	+0.4	+0.6	+1.0	+1.0								

Average difference +0.32° C.
Extreme differences +1.4° and −1.0° C.

sensible air-ground interface temperature is shown in figures 2 and 3. These are typical night runs. They compare the temperature indicated by the modified soil thermograph and by the copper plate with a No. 419 thermistor, with the temperature indicated by the bottom plate of a Suomi-Kuhn Economical Net Radiometer having No. 419 thermistors as sensors. The three instruments were exposed within 10 feet of each other in the center of a 50-foot circle of barren soil. The soil had been cultivated, sterilized with arsenic trioxide, and allowed to weather for about 5 months. It should be emphasized that the instruments were not sampling the same parcel of soil, but similar parcels. The data for figure 2 were obtained while the soil was dry, and for figure 3 while the soil was moist but not saturated.

Table 1 shows a comparison of the data obtained from a soil plate with a ¼-inch thermohm as a sensor, and the modified net radiometer using No. 405 Brown Weather Bureau radiosonde thermistors as sensors. The net radiometer was mounted directly above the soil plate in order to sample as nearly as possible the same parcel of soil surface. A continuous record was obtained on separate recorders during the week of November 29 through December 5, 1959. To reduce the possibility of bias, the data from each recorder were read off and recorded by different people on separate sheets of paper. These were then combined as shown in the table. Data for nighttime hours only were used since the bottom plate of the net radiometer is subject to effects of reflected short-wave radiation during daylight hours. Visual checking during this period showed no signs of moisture condensing between the Saran Wrap covers and no dew formation.

4. SOURCES OF ERROR

SOIL PLATE

In the discussion of possible errors which might be introduced into the measurement of the "sensible air-soil interface temperature" by means of the copper plate technique, errors peculiar to particular sensors are not discussed since this information is well covered in the literature.

A first source of error involves the diameter of the temperature sensor. As has been pointed out by Geiger [5], "in order to understand the heat economy of the earth it is necessary to know the temperature of the surface itself." In determining the sensible air-ground interface temperature, the smaller the diameter of the sensor the more nearly the copper plate can be constructed as a flat surface which will lie in direct contact with the surface of the ground.

A second factor which influences the accuracy of the measurement is the penetration of moisture into the sensor enclosure. It is important to make a waterproof seal around the sensor since in saturated conditions the sensor is effectively immersed in water and errors are introduced.

The third source of error is failure of the plate to maintain continuous contact with the ground. This problem is similar to that encountered with the thermocouples, but if the copper is of sufficient thickness to remain flat the problem is minimized.

A fourth source of error is the fact that the copper plate does not change color as the soil does when its moisture content fluctuates. On the average, however, the weathered copper plate takes on a color similar to that of the moist soil in this area.

A fifth source of possible error may be the differing effects of evaporation and condensation of moisture from the plate and the soil surface. The larger sensor used with the modified soil thermograph is not as sensitive to change in temperature as the thermistors and damps out most short-period fluctuation.

NET RADIOMETER

The temperature response of the bottom plate of the net radiometer is influenced by at least four sources of instrumental error. First, imperfect insulation may permit conduction of heat from the warmer to the colder plate. Thus at night the temperature reading of the bottom plate of the net radiometer may be too low because of conduction of heat upward through the insulation to the colder upper plate. This situation would be reversed during the daytime when the upper plate becomes the warmer. A conduction correction based on the temperature difference between the two plates can be determined, and this error source corrected for. Instrumentation for determination of the conduction constants was not available, so the uncorrected temperature readings were used.

Second, short-wave radiation reflected from the soil or snow surface during daylight hours causes the lower plate to have a higher temperature than the soil or snow surface which is radiating at a longer wavelength. This factor is not constant with the sun's altitude, but varies with the albedo of the surface, the amount and type of clouds, etc., and so can be considered only qualitatively.

Third, moisture tends to condense between the polyethylene or Saran Wrap layers covering the plates of the net radiometer. Since very thin layers of moisture in the form of liquid water absorb strongly in the infrared [8], nighttime observations are invalid if moisture is condensed between the layers of plastic or on the upper surfaces of the net radiometer covers. Because frequent changes of the covers were necessary, the radiometer could not be left unattended for long periods while its temperatures were being recorded. According to Kuhn [9] the moisture problem has been eliminated by flushing and sealing the unit with dry nitrogen.

A fourth source of possible error, for which no correction has as yet been determined, is the effect of wind upon the temperature indicated by the net radiometer. This effect is not particularly important when computing net radiation since the effect should be the same on both plates. When using the lower plate only, however, it is reasonable to assume that some correction should be applied. A simple test made by shielding one net radiometer from the wind and not shielding another showed that with wind speeds of 10 or 15 m.p.h. the correction may be of the order of several degrees. Kuhn [9] has eliminated the wind effects from the economical radiometer by ventilating with a cheap electric fan.

5. CONCLUSIONS

The soil plate technique gives quite satisfactory indications of the sensible air-ground interface temperature. The accuracy of the measurements depends, of course, on the reliability and sensitivity of the sensor, as well as upon the size. The soil thermograph gives adequate reliability, but is more sluggish than the other sensors tested.

The Suomi-Kuhn Economical Net Radiometer is satisfactory for test purposes and specialized studies, such as measurement of the effective temperature of snow cover at night, etc. It is subject to difficulties because of moisture condensation and the effect of strong winds.

The most satisfactory method tested of measuring the sensible air-ground interface temperature was the use of either a small thermohm or thermistor as a sensor, which gave continuous records of sufficient accuracy for temperature forecast studies. As has been indicated, no tests were made with thermocouples due to lack of proper recording equipment, but the use of the copper plate with a thermocouple sensor should give very satisfactory results. With a thermocouple it might be possible to reduce the size of the plate and at the same time maintain a better contact between the ground and the sensing element over a longer period of time than could be accomplished with a thermocouple alone.

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REFERENCES

1. C. P. Mook and S. Price, "Objective Methods of Forecasting Winter Minimum Temperatures at Washington, D.C.," *Research Paper* No. 27, U.S. Weather Bureau, Washington, D.C., 1947, 38 pp.
2. D. Brunt, *Physical and Dynamical Meteorology*, Cambridge University Press, London, 1939, pp. 136–142.
3. P. C. Kangieser, "Forecasting Minimum Temperatures on Clear Winter Nights in an Arid Region," *Monthly Weather Review*, vol. 87, No. 1, Jan. 1959, pp. 19–28.
4. J. G. Sinclair, "Temperatures of the Soil and Air in a Desert," *Monthly Weather Review*, vol. 50, No. 3, Mar. 1922, pp. 142–144.
5. R. Geiger, "The Climate Near the Ground," translated from the German of the second German edition of *Das Klima der Bodennaher Luftschicht*, Harvard University Press, Cambridge, Mass., 1950 (pp. 131–132).
6. K. R. Ramanathan, "On Temperatures of Exposed Rails at Agra," India Meteorological Dept., *Scientific Notes*, vol. I, No. 4, 1929, 12 pp.
7. V. E. Suomi and P. M. Kuhn, "An Economical Net Radiometer," *Tellus*, vol. 10, No. 1, Feb. 1958, pp. 160–163.
8. J. E. McDonald, "Absorption of Atmospheric Radiation by Water Films and Water Clouds," *Journal of Meteorology*, vol. 17, No. 2, Apr. 1960, pp. 232–238.
9. P. M. Kuhn, Private communication, University of Wisconsin, Madison, Wis., August 10, 1960.